5.0 DETAILED ANALYSIS OF ALTERNATIVES

The remedial alternatives developed in Section 4.0 and retained for the detailed analysis are evaluated in this section. The detailed evaluation of each remedial alternative includes the following:

- Refinement of the remedial alternative using quantitative data, where available.
- Detailed evaluation of the remedial alternatives emphasizing the criteria outlined in EPA guidance [EPA, 1988 (guidance for RI/FS)].
- Evaluation of the remedial alternatives with respect to the statutory preferences in CERCLA Section 121(b), as amended.

This stage is the most detailed in the evaluation process, and for this reason, the alternatives are defined more quantitatively.

5.1 EVALUATION OF ALTERNATIVES

The following criteria from EPA's RI/FS guidance document (EPA, 1988) are used as the basis for the detailed analysis:

- Overall Protection of Human Health and the Environment
- Compliance with ARARs
- Long-term Effectiveness and Permanence
- Reduction of Toxicity, Mobility, or Volume
- Short-term Effectiveness
- Implementability
- Cost
- State Acceptance
- Community Acceptance

Factors considered for each of the evaluation criteria are summarized in Table 5-1.

Of the nine evaluation criteria, only the first seven will be fully evaluated. State and community acceptance will be evaluated during State review of the draft FS, the public comment period, and the post-RI/FS meeting/public comment period. Also, as discussed in Section 1.0, this analysis is required when the presumptive remedy format is used.

The remedial alternatives retained in Section 4.0 for the detailed evaluation are as follows:

Alternative 1: No Action

Alternative 2c: In Situ SVE/Off-Gas Treatment with GAC

5.1.1 Alternative 1: No Action

The No Action alternative is included to provide a baseline for comparison with the other alternatives. No remedial activities are planned under this alternative except those that occur naturally. A soil-vapor monitoring program (currently in place) is used to track contaminant concentrations and areal extent in the soil vapor over time.

The monitoring program will consist of collection and analyses of soil-vapor samples from the soil vapor monitoring wells (see Figure 4-1) on a quarterly basis for 5 years. If VOC levels continue to decrease and/or remain stable, the frequency may be reduced to semi-annual or annual before the end of the 5-year period. At the end of the 5-year period, sampling will either be switched to annual or dropped entirely depending on data from the first 5 years. Agency approvals will be obtained for all monitoring strategies.

Overall Protection of Human Health and the Environment

Alternative 1 is protective of human health in terms of exposure to contaminants via direct contact with soils, based on results of the human health risk assessment (Foster Wheeler, 1999b).

Mitigation of potential human health risks associated with exposure to groundwater is being considered in the OU-1/OU-3 FS. Furthermore, it is noted that groundwater extracted by the local purveyors for domestic consumption is currently being treated to meet strict regulatory requirements. Risks associated with the groundwater in the OU-1/OU-3 risk assessment were based on exposure to untreated water, which in reality, never occurs. This has been confirmed by the Agency for Toxic Substances and Disease Registry (ATSDR), which issued a report in 1998 stating that, in effect, there were no human health risks associated with groundwater at the site. It is acknowledged, however, that Alternative 1 is not protective of groundwater because of migration of VOCs from vadose zone soils to groundwater.

Compliance with ARARs

ARARs established for the JPL OU-2 site are presented and discussed in Section 2. As expected, this alternative does not meet chemical-specific ARARs since the constituents of interest are left in place and groundwater beneath the site is not protected. This alternative does meet location-specific ARARs since it does not involve construction activities. It also meets action specific ARARs. In particular, soil vapor monitoring will be used in accordance with RWQCB guidelines.

Long-Term Effectiveness and Permanence

This alternative is not effective over the long-term because the soil contamination continues to migrate into the groundwater. However, human health is protected in the long-term with regard to surface soils based on results of the OU-2 Human Health Risk Assessment.

Reduction of Toxicity, Mobility, and Volume

No remedial treatment is planned with this alternative; therefore, there is no reduction in toxicity, mobility, and volume of contamination in JPL OU-2 soils. While there will be some natural attenuation that reduces the overall toxicity, mobility, and volume of constituents of interest, its impact is not expected to be significant.

Short-Term Effectiveness

Because this alternative is the No Action alternative, no activities are planned. Hence, there are no short-term risks to the community resulting from implementation activities.

Implementability

This alternative is easily implemented since there are no activities associated with Alternative 1.

Cost

The only costs associated with this alternative are those relating to the soil monitoring program. Costs were estimated based on quarterly sampling events for the first 5 years, followed by 25 annual events. Based on these parameters, the approximate cost estimate for Alternative 1 is $1,477,000. Cost calculations are provided in Appendix B. It should be noted that the durations for the quarterly and annual sampling (5 and 25 years) are conservative, and they may be reduced significantly depending on the data obtained.

5.1.2 Alternative 2c: In Situ SVE/GAC Off-Gas Treatment

Alternative 2c uses in situ SVE to treat VOCs in soils in OU-2. For the purpose of this FS, it is assumed that up to 5 new vapor extraction wells, and up to 5 new extraction and treatment systems will be required. It should be noted that while 5 wells have been assumed for the purpose of this FS, the actual number of wells for the full-scale system will be determined during the remedial design phase. The full-scale system will be designed to be protective of groundwater and comply with RWQCB (1996) requirements.

The new wells will be screened similar to the existing well, and will have up to three discrete screens. The depth and extent of the screens will depend on the well's location, and will take into account the variations in water level at the site. At least one screen may extend to depths that are below the "high" water table. Such screens would be operated only when water table is lower than the bottom of the screen, thereby effecting VOC removal from soils that are below water table during wet periods.

The actual number of wells will depend on the results of the SVE pilot test, and the extent of VOC contamination. The systems would be operated until sufficient VOC mass reduction is effected, as evidenced by conformance with specific criteria, which will be determined and agreed upon during the remedial design phase.

Also, it is recognized that there is some uncertainty regarding VOC levels to the west of soil vapor well No. 36. Given the RORI of 400 feet, VOCs to the west of soil vapor well No. 36, if any, will be captured by an appropriately placed extraction well.

Alternative 2c includes the same soil vapor monitoring program as described for Alternative 1. Results from the soil-vapor analyses will be used to determine the extent of remediation, if operations should be adjusted, or if a new approach must be taken for the remainder of the remediation. Adjustments include shutting down wells or selected screens within specific wells to enhance remediation.

Overall Protection Of Human Health and the Environment

Alternative 2c is protective of human health from the standpoint that the VOCs in the vadose-zone soils do not pose a threat to human health because there are no direct exposure pathways. The groundwater beneath the site is protected through remediation of the vadose zone, which limits future migration of VOCs to the water table. Treatment of the off-gas stream further protects the environment by removing VOCs before the off-gas stream is released into the atmosphere.

Compliance with ARARs

Alternative 2c is in compliance with all identified chemical-specific, action-specific, and site-specific ARARs as discussed below.

Alternative 2c is in compliance with the chemical-specific ARARs identified in Section 2.0. The MCLs for groundwater are indirectly applicable since SVE will be implemented in a manner that meets the stated RAO of protecting groundwater. The PRGs and SSLs (which are TBCs, see Table 2.1) were used in the risk assessment during the RI (see Section 1.3.9.1). The RWQCB's approach to investigation and clean-up of soil (a TBC) addresses all of the remaining RWQCB ARARs (i.e., this approach is designed to take these ARARs into account).

Location-specific ARARs will be taken into account during the remedial design phase (see Table 2-1). Specifically, as noted in Table 2-1, wastes will be managed in accordance with the Federal Facilities Compliance Act (soil cuttings, decontamination solutions, etc.). System facilities will be situated outside the 100-year flood plain of the Arroyo Creek. Potential locations will be surveyed for historic, archeologic, architectural, and cultural resources during design.

All of the chemical-specific ARARs pertaining to discharge of air will be addressed by the GAC treatment system. Dust generated during well installation (and piping installation, if below grade) will be controlled. The spent carbon and wastewater (entrained moisture in extracted vapor) will be profiled and appropriately disposed. The RWQCB's standards for SVE operation and soil-vapor sampling will be followed.

Long-Term Effectiveness

Alternative 2c is effective in the long-term. The SVE process permanently removes VOCs from the vadose zone. The VOC-laden air is processed through the vapor-phase GAC, which in turn permanently removes the VOCs from the extracted soil vapor. The VOCs are subsequently removed from the carbon, either through thermal regeneration in which the VOCs are destroyed, or through chemical regeneration in which the VOCs are transferred to the regenerating solution. Because contaminants are permanently removed from the soil, existing and future risks to groundwater are reduced. Once remediation is completed (based on RWQCB requirements), residual VOCs would not be expected to further impact groundwater, and, thus, long-term reliability is achieved.

Reduction of Toxicity, Mobility, and Volume

This alternative permanently and irreversibly removes VOCs from the vadose zone, thus, reducing the volume and mobility of contamination in the soil. Based on pilot study results, the amount of mass removal is expected to be significant. As discussed in Appendix A, the pilot test, which was conducted on an extraction well located in the center of the VOC plume, has already resulted in removal of 1,050 pounds. This removal has caused VOCs in soil-vapor monitoring wells to reduce significantly. Reductions of over 80 percent were observed in sampling tips 400 feet away from the extraction well. The amount of reduction decreased with distance from the well (see Appendix A). Thus, this alternative will reduce the volume of VOCs in the subsurface. In addition, shutdown of the system will be based on RWQCB criteria (RWQCB, 1996) which is designed to ensure that impact to groundwater is minimal.

The mobility of VOCs will be reduced within the zone of influence of the extraction well(s), since these VOCs would move towards the extraction well, and eventually be captured by the well. While there is no direct reduction in toxicity as a result of this alternative, the decrease in VOC-vapor volume results in reduction of the amount of toxic material.

Thus, Alternative 2c meets this criterion.

Short-Term Effectiveness

In situ SVE presents very few risks to on-site workers or the community with the exception of possible dust generation during well installation.

Equipment and operations for in situ SVE systems are readily available. The proposed SVE system will be designed such that the wells and the associated piping is under vacuum at all times (the extracted vapor will be "pulled" through carbon vessels by the extraction blower). The portions of the piping that are under pressure will only contain treated vapor. The treatment of the vapors with GAC will remove the majority of the VOCs, thereby minimizing VOC emissions to the atmosphere.

Thus, Alternative 2c meets this criterion.

Implementability

In situ SVE is one of the most commonly used remedial processes for treatment of VOC contamination in soil. Required equipment is readily available from many sources and does not require specialized knowledge for installation. Installing and operating vapor extraction wells requires fewer engineering controls than other technologies such as excavation and incineration, and no difficulties are foreseeable with regard to obtaining approvals from the various agencies.

GAC is the most widely used off-gas treatment for SVE systems. Treatment units are readily available and installation and operation are not difficult. Because the waste (spent carbon) is routinely transported and treated off-site, there are no anticipated issues regarding on-site waste storage and/or disposal services.

Soil vapor sampling is a proven technology, has been successfully tested at JPL, and is readily implemented particularly since numerous soil vapor sampling tips are already in place.

Thus, Alternative 2c meets this criterion.

Cost

Costs associated with this alternative include extraction-well installation, vacuum blowers, well-head GAC units, and the soil monitoring program.

Capital costs include installation of five new extraction wells that would be similar in construction to the existing pilot test extraction well (averaging 200 feet deep and each having three discrete screened intervals). Each well will be equipped with a 500-cfm blower and up to four GAC vessels containing 2,000 pounds of carbon each. Operating and maintenance costs cover power consumption for the blowers and carbon replacement/regeneration for the GAC units. The major pieces of equipment are expected to last for the duration of the treatment period without replacement.

Site engineering and planning are included as 15 percent of the construction cost and a 25 percent contingency is included. A present worth value for this alternative was determined using a 5 percent discount rate and assuming that the SVE system will operate for 5 years. The soil vapor monitoring component is assumed to be the same as for Alternative 1 (i.e., 5 years of quarterly monitoring followed by 25 years of annual monitoring). It should be noted that these durations (for both system operation and monitoring) are conservative and may be reduced depending on the ongoing soil vapor monitoring results.

Based on these parameters, the cost estimate for Alternative 2c is approximately $3,816,600. Cost calculations are presented in Appendix B.

5.2 COMPARATIVE ANALYSIS

Contained in this section is a comparative analysis of the alternatives with respect to each of the seven evaluation criteria. The comparative analysis provides the basis for identifying a preferred alternative for the JPL OU-2 site. A summary of the comparative analysis is presented in Table 5-2.

5.2.1 Overall Protection of Human Health and the Environment

This evaluation criterion involves assessing the degree to which each alternative provides adequate protection of human health and the environment. For this FS, both alternatives are considered protective of human health with regard to exposure to contaminants via direct exposure to soil. This is because the risk assessment indicated that the VOCs in surface soil do not pose a risk to humans. The focus is, therefore, a comparison of how well the alternatives protect the environment, specifically the groundwater. The VOCs in soils have migrated to the water table and are currently impacting groundwater quality. Protection of the environment is taken to be the inhibition of further groundwater contamination.

Alternative 1, the No Action alternative, relies on natural attenuation to reduce VOC concentrations in the vadose zone. This provides negligible protection of the environment. Alternatives 2c uses in situ SVE to remove VOCs from the contaminant plume in soil. This is substantially more protection than is offered by Alternative 1.

5.2.2 Compliance with ARARs

This evaluation criterion is used to evaluate how well each alternative conforms to federal and state ARARs or whether there is adequate justification for invoking waivers to specific ARARs. The ARARs for these remedial alternatives are described in Section 2.

Alternative 1 does not comply with ARARs since there is no VOC removal. Alternative 2c meets all ARARs as discussed in Section 5.1.2.

5.2.3 Long-Term Effectiveness and Permanence

Long-term effectiveness relates to the amount of risk remaining at the site after the remedial action objectives are met. At this site, risk will be reduced if continued migration of contaminants to groundwater is prevented, which is the only concern at this site for OU-2. Alternative 1 does not prevent migration of contaminants into groundwater and offers negligible long-term effectiveness and permanence. Alternative 2c is effective in the long-term because it permanently removes VOCs from the vadose zone.

Both alternatives include longer-term soil vapor sampling for, possibly, up to 30 years. The sampling program poses minimal risks to the community, the environment, or to workers involved in handling environmental samples.

5.2.4 Reduction in Toxicity, Mobility, and Volume

This criterion is a measure of the reduction in toxicity, mobility, and volume of the constituents of interest at a site and also the extent to which the reduction is irreversible. Alternative 1 does not include any treatment, so there is no reduction in toxicity, mobility, or volume except for minor reductions provided by natural attenuation.

Alternatives 2c provides significant reduction in volume by permanently and irreversibly removing VOCs from the vadose zone. This reduces the mobility of the contaminants and the volume of contamination in the soil.

5.2.5 Short-Term Effectiveness

Short-term effectiveness is a measure of the impacts to workers, the community, and the environment during the construction and operating life of the remedial action. Because Alternative 1 does not include either construction or operation of a treatment system, there are no effects on the community, workers, or the environment. For these reasons, Alternative 1 has very few impacts in the short term.

Alternative 2c relies on in situ SVE for treatment, and requires installation of up to five new soil vapor extraction wells. Short-term impacts to workers and the community are limited to possible dust releases during well installation, which would have a negligible impact. SVE system operation would also result in negligible impacts since the system is in situ. The only waste streams generated include spent GAC and entrained water (entrained moisture, which is separated using a knockout tank). VOCs in the off-gas stream are permanently removed from the stream, and emissions will comply with air emission standards. Therefore, Alternative 2c results in only slightly higher short-term risks than the No Action alternative.

5.2.6 Implementability

Implementability is a measure of how easily a remedial action can be installed and operated. At the JPL OU-2 site, Alternative 1 is the easiest alternative to implement because no construction activities are performed.

Implementation of the in situ SVE systems for Alternative 2c is relatively straightforward in that this is the most commonly used process for treating VOC contamination in soil. Required equipment is readily available from many sources and does not require specialized knowledge for installation.

5.2.7 Cost

Cost considerations include capital costs and O&M costs as well as the cost of the soil vapor monitoring program.

Alternative 1 is the least expensive alternative since no activities are planned under this alternative except soil-vapor monitoring. The estimated total cost for Alternative 1 is approximately $1,477,000.

The estimated total cost for Alternative 2c is approximately $3,816,600. This includes installation of the five new vapor extraction wells, five new vapor extraction and treatment systems, operation and maintenance of the existing and new systems for a 5-year period, quarterly soil-vapor monitoring for first 5 years, and annual soil-vapor monitoring for 25 years.

5.3 PREFERRED ALTERNATIVE

Alternative 1, No Action, is not appropriate for the site because no protection of groundwater is provided, and, therefore, the RAO for the site will not be met. Based on the preceding analysis of alternatives, Alternative 2c, In Situ SVE/GAC Off-Gas Treatment, is chosen as the preferred alternative for the JPL OU-2 site.

TABLES

TABLE 5-1

FACTORS FOR DETAILED EVALUATION OF ALTERNATIVES

Overall Protection	How alternative provides human health and environmental protection.
Compliance with ARARs	Compliance with chemical-specific ARARs. Compliance with location-specific ARARs. Compliance with action-specific ARARs. Compliance with other criteria, advisories, and guidance.
Long-Term Effectiveness and Permanence	Reduction of existing risks. Magnitude of future risks. Long-term reliability. Prevention of future exposure to residuals.
Reduction of Toxicity, Mobility, and Volume Through Treatment	Amount of hazardous materials destroyed or treated. Degree of expected reductions in toxicity, mobility, and volume. Degree to which treatment is irreversible. Type and quantities of residuals remaining after treatment.
Short-Term Effectiveness	Time until protection is achieved. Short-term reliability of technology. Protection of community during remedial actions.
Implementability	Ability to operate and construct the technology. Ability to phase into operable units. Ease of undertaking additional remedial actions, if necessary. Ability to monitor effectiveness of remedy. Ability to obtain approvals from other agencies. Coordination with other agencies. Availability of treatment, storage, and disposal services and capacity. Availability of necessary equipment and specialists.
Cost	Construction costs. Operating costs for implementing remedial action. Other capital and short-term costs until remedial action is complete. Costs of operation and maintenance for as long as necessary. Costs of 5-year reviews (if required).
State Acceptance(1)	Features of the alternative the state supports. Features of the alternative about which the state has reservations. Features of the alternative the state strongly opposes.
Community Acceptance(1)	Features of the alternative the community supports. Features of the alternative about which the community has reservations. Features of the alternative the community strongly opposes.

Notes:

(1): Not evaluated in feasibility study because of limited available information. State and community acceptance will be fully addressed in the record of decision (ROD).

TABLE 5-2

DETAILED SCREENING OF ALTERNATIVES

	Alternative 1	Alternative 2c	Comments
Description	• No Action • Soil-Vapor Monitoring	• *In Situ* SVE • GAC Off-Gas Treatment • Soil-Vapor Monitoring	
Overall Protection	• Not protective of environment.	• Protective of environment.	• Protection of human health not needed because no human receptors at this site. Alternative 2c indirectly provides protection by reducing VOCs in the subsurface soils, which in turn reduces the potential for further impact to groundwater.
Compliance with ARARs	• Does not comply with ARARs	• Complies with ARARs	• Compliance for Alternative 2c is either direct, or through design of full-scale SVE systems.
Long-Term Effectiveness	• Not effective in long-term. • Constituents of interest remain at site and will be released to groundwater.	• Very effective in long-term. • Constituents of interest permanently removed from vadose zone.	
Reduction of Toxicity, Mobility, or Volume	• No reduction in toxicity, mobility, or volume of constituents of interest.	• Nearly complete reduction in volume of constituents of interest through SVE. GAC removes, but does not destroy constituents of interest.	• COPCs are transferred to VPGAC for Alternative 2c, but are subsequently removed during regeneration.
Short-Term Effectiveness	• Extremely high short-term effectiveness. • No risks to workers, community, or environment.	• High short-term effectiveness. • Few risks to workers, community, or environment.	• Alternative 1 has highest short-term effectiveness. Alternative 2c highly effective in short-term.
Implementability	• Very easily implemented. • No activities required.	• Easily implemented. • SVE is well-known treatment system. • GAC also well-known, easily implemented.	• Alternative 1 is most easily implemented. • Alternative 2c is easily implemented due to wide acceptance of GAC for off-gas treatment.
Cost	• Approximate cost: $1,477,000	• Approximate cost: $3,816,600	• Alternative 1 is least expensive. • Alternative 2c is most expensive.
Conclusion	• Does not pass first two criteria (threshold criteria).	• Preferred alternative.	• Meets RAOs, complies with ARARs in a cost-effective manner.

Notes:

ARAR – Applicable or relevant and appropriate requirement
COPC – Constituent of potential concern
GAC – Granular activated carbon
RAO – Remedial action objective
SVE – Soil vapor extraction
VOC – Volatile organic compound
VPGAC – Vapor-phase granulated activated carbon

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APPENDIX A

SUMMARY REPORT
SOIL VAPOR EXTRACTION PILOT TEST

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ACRONYMS AND ABBREVIATIONS

amsl	Above mean sea level
bgs	Below ground surface
CCl_4	Carbon tetrachloride
cfm	Cubic feet per minute
1,1-DCA	1,1-Dichloroethane
1,1-DCE	1,1-Dichloroethene
1,2-DCA	1,2-Dichloroethane
DTSC	California Department of Toxic Substances Control
EPA	U.S. Environmental Protection Agency
Freon 113	Trichlorotrifluoroethane
ft	feet
GAC	Granular activated carbon
H_2O	Water
in.	Inch or inches
in. H_2O	Inches of water
JPL	Jet Propulsion Laboratory
lb	Pound
lbs/hr	Pounds per hour
NASA	National Aeronautics and Space Administration
OU-2	Operable Unit 2 (On-Site Contaminant Source Investigation)
PVC	Polyvinyl chloride
RI/FS	Remedial investigation/feasibility study
ROI	Radius of influence
RORI	Radius of remedial influence
RPM	Remedial Project Manager
RWQCB	California Regional Water Quality Control Board, Los Angeles Region
SVE	Soil vapor extraction
TCE	Trichloroethene
VOC	Volatile organic compound

1.0 INTRODUCTION

Presented in this summary report are the results of a long-term soil vapor extraction (SVE) pilot test conducted in Operable Unit 2 (OU-2) at National Aeronautics and Space Administration's (NASA's) Jet Propulsion Laboratory (JPL) facilities. These facilities are located at 4800 Oak Grove Drive in Pasadena, California and are referred to as "JPL" throughout the rest of this document. Figures A.1-1 and A.1-2 are a Site Location Map and Site Facility Map for the site, respectively.

The test was conducted in the parking lot located between Buildings 18 and 79 (Figure A.1-2). Based on previous investigations at the site, subsurface soils in OU-2 are known to be impacted with volatile organic compound (VOC) vapors, primarily carbon tetrachloride (CCl_4). The Remedial Investigation/Feasibility Study (RI/FS) Work Plan (Ebasco, 1993) and its addenda (Foster Wheeler, 1996a and 1996b) identified the investigative work required to adequately characterize the impacted soil. The investigative work identified in the RI/FS Work Plan consisted of installation and sampling of nested soil vapor monitoring wells. The sampling of these wells has indicated the presence of VOC vapors including CCl_4, chloroform, Freon 113, trichloroethene (TCE), 1,1-dichloroethane (1,1-DCA), 1,2-dichloroethane (1,2-DCA), and 1,1-dichloroethene (1,1-DCE).

Based on the soil types at JPL and the nature and extent of contamination, in situ SVE appears to be a feasible technology for remediating the VOC impacted soils in OU-2. In situ SVE was one of the in situ technologies identified as a potential remedial technology for OU-2 in the 1993 RI/FS Work Plan. During ongoing Remedial Project Manager (RPM) meetings (September 4, 1997, and December 3, 1997) attended by representatives from NASA, JPL, Foster Wheeler Environmental Corporation (Foster Wheeler), the U.S. Environmental Protection Agency (EPA), the California Regional Water Quality Control Board, Los Angeles Region (RWQCB), and the California Department of Toxic Substances Control (DTSC), it was agreed that a pilot test would be conducted to confirm the feasibility of using in situ SVE at the site. In addition, the pilot test would also provide design criteria for implementing a full-scale SVE system at the site. The entire test, including setup and demobilization, was initially expected to require approximately 9 weeks to complete. The initial test was to run in two test phases, Test 1 and Test 2.

The test was started in April 1998 and conducted through June 1998 in accordance with the SVE pilot test work plan contained in Addendum Number 2 to the Field Sampling and Analysis Plan for Performing a Remedial Investigation at Operable Unit 2 (Foster Wheeler, 1998). Based on the results of the test it was decided to extend the test for an additional 9 months, as discussed during the RPM Meeting on July 16, 1998. During the extended portion of the test, noted as the third test phase (Test 3), the SVE system operated from November 1998 and continued, with exception of a few temporary shutdowns, through September 1999. Since then, the SVE system has been placed on standby.

Presented in this report are the scope of the pilot test, equipment used for the test, test procedures, and a summary of the data obtained from the test. A supplementary report will be submitted upon completion of the test.

1.1 PILOT TEST OBJECTIVES

The objectives of the SVE pilot test were to:

- Confirm the feasibility of using SVE at JPL.
- Estimate physical design parameters, such as SVE flow rate from the extraction well at different extraction vacuums, radius of influence (ROI) of a single extraction well, and permeability of the soil to air flow.
- Evaluate VOC concentrations in extracted vapor.

1.2 SCOPE OF WORK

To meet the above objectives, one pilot test well (VE-1) with three discrete screened intervals was installed. Twelve existing monitoring points (with multiple sample ports) in the vicinity of this well were used for monitoring purposes. Additional details regarding the test well and the monitoring points are provided in Section 2.0.

The scope of work required to meet the project objectives consisted of three test phases:

1. Test 1 – Short-term tests: three on individual screens, one on all three screens combined.
2. Test 2 – Long-term test on two combinations of screens: one on all three screens combined and one on Screens B and C combined.
3. Test 3 – This was a continuation of Test 2 on Screens B and C combined and Screen C separately.

In addition, VOC concentrations in individual screens and soil vapor monitoring points were monitored periodically to provide additional data pertaining to SVE effectiveness.

Test 1 was started on April 13, 1998, and was completed on May 7, 1998. Test 2 was started on May 11, 1998, and was completed on June 10, 1998. Test 3 was started on November 2, 1998, and was shut down on September 22, 1999. The SVE system is currently on standby.

1.3 REPORT ORGANIZATION

The remainder of the Report is organized into the following sections:

Section 2.0 – Equipment and Materials: describes the equipment and materials used for the test.

Section 3.0 – Test Procedures: describes the general test procedures performed during Test 1, Test 2, and Test 3.

Section 4.0 – Results and Data Analysis/Interpretation: describes the results of the data collected and various data analyses to meet the project objectives.

Section 5.0 – Conclusions: summarizes conclusions of the SVE pilot test.

Section 6.0 – References.

2.0 EQUIPMENT AND MATERIALS

This section provides descriptions of the extraction well, monitoring wells, and treatment/ sampling equipment used in the SVE pilot test.

2.1 WELLS

During the course of the SVE pilot test, two types of wells were used: a SVE well and monitoring wells. The location of these wells is shown in Figure A.1-2.

2.1.1 Extraction Well

A single vapor extraction test well (VE-1) was used for the SVE pilot test. It is located approximately at the center of the highest soil-vapor contamination. The well consists of three discrete screened intervals (i.e., three separate casings in the same borehole) with a bentonite seal between screens. The screens are designated shallowest to deepest as VE-1A (Screen A), VE-1B (Screen B), and VE-1C (Screen C), respectively. Each casing is constructed of Schedule 80 PVC, and is screened (0.020 inch slots) from 44 to 84 feet below ground surface (bgs), 94 to 134 feet bgs; and 145 to 185 feet bgs as shown in Figure A.2-1. Screens A, B, and C each have inside diameters of 2 inches. The annular space between the screens and the borehole is backfilled with Lonestar RMC® No. 3 sand, and the annular space between the blank casing and the borehole is filled with Enviroplug® No. 16 bentonite granules.

2.1.2 Monitoring Wells

Twelve soil vapor monitoring wells (SVW-25, -26, -27, -28, -32, -33, -34, -35, -36, -37, -38, and -39) were used for monitoring (Figure A.1-2). Each well contains discrete depth-specific monitoring points. These were used to monitor vacuum responses and to collect depth-specific soil vapor samples during the test. In total, there were 110 depth-specific monitoring points available. However, because of the fluctuating water table and other unknown factors, some of the probes were plugged and, therefore, were not continuously monitored. Also, access to some of the soil vapor monitoring wells was not always available.

2.2 EXTRACTION/TREATMENT EQUIPMENT

The following subsections provide a description of the extraction/treatment equipment. Figure A.2-2 shows a piping and instrumentation diagram for the pilot test equipment.

2.2.1 Blower Package

Tests 1 and 2

Because of restrictions imposed by the South Coast Air Quality Management District (SCAQMD) Permit to Operate (PTO) (Multiple Locations Permit), extraction blowers operating at the site were limited to a maximum flow rate of 200 cubic feet per minute (cfm) per unit. Hence, two units were used in parallel during the last week of Test 1 and for the entire duration of Test 2. Both extraction systems met the following specifications:

- One trailer mounted, one skid mounted.
- Common 50-gallon knockout tank, level switch, and safety interlock to shut down blower for high water level.
- Vacuum blower, maximum flow 200 cfm, maximum vacuum equivalent to 10 inches of mercury. Blowers 1 and 2 operated at a maximum flow rate of 200 cfm and 100 cfm, respectively.
- Dilution air valve and recirculation air valve to regulate vacuum and flow.

Test 3

For Test 3, the above-mentioned equipment was replaced with a single 20-horsepower positive displacement blower package (skid-mounted). Temporary power connections were provided by JPL.

2.2.2 Treatment System

Tests 1 and 2

The treatment system in Tests 1 and 2 consisted of two 1,000-pound (lb) vapor-phase granular activated carbon (GAC) vessels in series per blower unit (four vessels total). This met the vendor's SCAQMD PTO requirements.

Test 3

The treatment system in Test 3 consisted of two parallel trains of two 2,000-lb vapor-phase GAC vessels in series (four vessels total). In May 1999, the vapor-phase GAC vessels were replaced with vapor-phase GAC vessels fitted with reinforcement boards to withstand higher vacuums.

2.3 SAMPLING/TESTING EQUIPMENT

Various sampling/testing equipment was used for the test, as follows:

- Flow Meter – to measure extracted flow rates.
- Flame Ionization Detector – to analyze extracted soil vapors and treated effluent.

- Tedlar Bags/Summa Canisters – to collect vapor for laboratory analyses.
- Sample Pumps – to collect soil vapor samples.
- Vacuum Gauges – to measure vacuums.
- Vacuum Chamber – to collect vapor samples from the extraction wells and piping while the system was in operation, without contaminating the sample pump.

3.0 TEST PROCEDURES

A general outline of the procedures followed during the performance of Tests 1, 2, and 3 are provided in the following subsections.

3.1 TEST 1 PROCEDURE

Test 1 consisted of applying a vacuum to each of the three-screened intervals of the extraction well individually and all three screens combined (four runs total). During each run, applied vacuum levels were varied on a day-to-day basis. Each vacuum level was applied for an 8-hour day, requiring each run 1 week to complete (baseline sampling/monitoring was performed on day 5). Test 1 ran for 4 weeks total. The vacuum application schedule is further outlined below.

Week	Screen	Day 1	Day 2	Day 3	Day 4
1	VE-1A	Maximum Vacuum	75 percent Maximum Vacuum	50 percent Maximum Vacuum	25 percent Maximum Vacuum
2	VE-1B	Maximum Vacuum	75 percent Maximum Vacuum	50 percent Maximum Vacuum	25 percent Maximum Vacuum
3	VE-1C	Maximum Vacuum	75 percent Maximum Vacuum	50 percent Maximum Vacuum	25 percent Maximum Vacuum
4	VE-1ABC	Maximum Vacuum	75 percent Maximum Vacuum	50 percent Maximum Vacuum	25 percent Maximum Vacuum

Soil vapors were extracted using a single 200 cfm blower and treated using two 1,100-pound carbon vessels in series. Two blowers (an additional 100 cfm blower was added), each followed by a series of carbon vessels (four 1,100-lb carbon vessels total) were used during Week 4 of testing. Field measurements were divided into three categories, Tests 1 and 2: Extraction Well Data (Attachment 1), Tests 1 and 2: Monitoring Well Data (Attachment 2), and Tests 1 and 2: Laboratory Results (Attachment 3). Extraction well data measurements were collected at the extraction well. These measurements included vacuum pressures, flow rates, and extracted vapor concentrations prior to carbon treatment (influent) and after carbon treatment (effluent). In addition, laboratory samples were collected at a minimum of twice per day. All laboratory samples were analyzed for VOCs by EPA Methods 8010/8020 in accordance with RWQCB protocols. Monitoring well data consisted of vacuum response readings at nearby soil vapor monitoring wells SVW-25, -26, and -28. Each monitoring well has a series of depth specific probes where measurements were taken.

3.2 TEST 2 PROCEDURE

Test 2 represented the initial portion of the long-term SVE test. The system was operated continuously for a period of 1 month. Over the first 3 weeks, vacuum pressure of approximately 26 inches of water (in. H_2O) was applied to Screens A, B, and C concurrently, using two blowers. The effluent from each blower was treated by two carbon vessels in series (four 1,100-lb carbon vessels total). During the final week of Test 2, the same vacuum was applied only to Screens B and C concurrently using only one blower[1]. Extracted vapors were treated through a series of two carbon vessels initially and through three carbon vessels during the final days of operation because of potential breakthrough in the primary carbon vessel. Field measurements were essentially identical to those collected during Test 1 and are also presented in Attachments 1, 2, and 3. Toward the end of Test 1, vacuum responses were observed in some of the more distant soil vapor monitoring wells. Hence, for Test 2, vacuum response measurements were also taken at SVW-28, -32, -33, -34, -35, -37, and -38. As can be seen from Figure A.1-2, these are at significant distances from VE-1.

3.3 TEST 3 PROCEDURE

Test 3 represents the final (extended) portion of the long-term SVE test. Test 3 was started on November 2, 1998, shut down on September 22, 1999, and is currently on standby. Vacuum was initially applied only on Screens B and C combined. This optimal combination was chosen after analyzing VOC removal data (see Section 4.0 for data analysis) and based on literature (Shan and others, 1992). During the later portion of the test, vacuum was applied only to Screen C. As with Test 1, field measurements were divided into three categories, Test 3: Extraction Well Data (Attachment 4), Test 3: Monitoring Well Data (Attachment 5) and Test 3: Laboratory Results (Attachment 6). The field measurements are very similar to the data collected during Test 1; however, additional vacuum reading and one additional soil vapor monitoring well (SVW-39) was added. Based on the data review of the initial 3 weeks of operation, the field measurement collection frequency was decreased from that in Tests 1 and 2.

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[1] This was necessitated by mechanical problems with one of the blowers.

4.0 DATA ANALYSIS / INTERPRETATION

Presented in this section are the various data collected to date during the SVE pilot test and an interpretation of this data. All figures generated for Section 4.0 were produced from data in Attachments 1 through 6.

4.1 TEST 1

The primary objective of Test 1 was to determine the effect of applied vacuum on the extraction well screens. Results generated from the data gathered in Test 1 include: vacuum to flow correlations, vacuum response with respect to distance from the extraction well, soil permeability, and VOC removal rates with respect to applied vacuum.

4.1.1 Vacuum versus Flow

As described earlier, Test 1 consisted of applying vacuums to Screens A, B, and C individually and then to Screens A, B, and C combined for four runs at four 8-hour days per run. On day 1 of each run, the blowers were set at maximum capacity. The blower capacity was reduced by 25 percent on day 2, 50 percent on day 3, and 75 percent on day 4 of each run (Table A.3-1). Test 1 extraction well data indicates that extraction flow rates decreased as applied vacuum decreased. Results are plotted as Figure A.4-1 and are discussed in the remainder of this section. Figure A.4-1 was generated based on data presented in Attachment 1.

The maximum applied vacuum to Screen A was recorded at 44 in. H_2O, which produced an extraction flow rate of 174 cfm. As the applied vacuum was reduced (25 percent increments), the flow rate also decreased as expected. The maximum applied vacuum to Screen B was recorded at 70 in. H_2O, which produced an extraction flow rate of 167 cfm. Similar to Screen A, as the applied vacuum on Screen B was reduced the flow rate also decreased. The maximum applied vacuum to Screen C was recorded at 80 in. H_2O, which produced an extraction flow rate of 157 cfm. Applied vacuum to flow rate response was fairly similar to that of Screen B. The results suggest that when extracting from individual screens, Screen A requires the least applied vacuum to produce a given flow rate, while Screen C requires the most applied vacuum to produce the same flow rate.

The maximum applied vacuum to Screens A, B, and C combined was recorded at 25 in. H_2O, which produced an extraction flow rate of 277 cfm.

4.1.2 Vacuum Responses

Responses to the applied vacuum at the extraction well were measured at various soil vapor monitoring wells within the vicinity of VE-1. As described in Section 2.1.2, each soil vapor monitoring well contains several depth-specific probes. The probes were used to measure vacuum responses at various depths and distances from the extraction well. Four monitoring zones, based on elevation, have been designated for the purpose of data analysis (Figure A.4-2). Zone 1 includes the subsurface areas at an elevation greater than 1,151 feet above mean sea level (amsl); Zone 2 covers the elevation interval of 1,151 feet to 1,101 feet amsl; Zone 3 covers the elevation interval of 1,051 feet to 1,001 feet amsl; and Zone 4 covers the elevation interval of 1,051 feet to 1,001 feet amsl. Elevations for Zones 2, 3 and 4 were designated to correspond to screened interval elevations at Screens A, B, and C [Screen elevations: A (1,146 feet to 1,106 feet.), B (1,096 feet to 1,056 feet), C (1,046 feet to 1,006 feet)], respectively. For a given monitoring well, the responses at the probes (for each zone) were averaged. Thus, for each monitoring well there is one "average" vacuum response for each of the four zones.

It should be noted that the locations of the three screens (A, B, and C) were selected based on the depth of the VOC-impacted zone only, and do not reflect site geology. Similarly, Zones 2, 3, and 4 correspond to the same depths as screens A, B, and C, respectively. Zone 1 corresponds to the unscreened portion of the extraction well.

During Test 1, responses were measured in monitoring wells SVW-25, -26, and -28. The results were plotted with respect to distance from VE-1 for all the extracting scenarios (Figures A.4-3 through A.4-6). As expected, the figures show that average vacuum responses were generally highest in the zone that corresponds to the extracting well screen and decreased with distance. For example, Figure A.4-3 illustrates that while extracting from Screen A, the greatest average vacuum responses were noted in Zone 2. Overall, Zone 1 showed the least average vacuum responses, which is expected since there is no extraction screen at the Zone 1 elevation. To some extent, this indicates that surface leakage is minimal based on the lack of responses in Zone 1 for the two closest soil vapor monitoring wells. This may be attributable to the fact that almost 90 percent of JPL is capped. Furthermore, as discussed later, vacuum responses during Tests 2 and 3 were noted in wells at a significant distance from VE-1, which again points to minimal surface leakage.

Based on Figure A.4-3, while extracting from Screen A, Zone 2 showed good vacuum responses in all three monitoring wells. Vacuum response averages in Zone 2 ranged from 0.7 in. H_2O to 1.8 in. H_2O. Zones 1, 3, and 4 did not show good responses with the exception of Zone 1 at well SVW-26 (response of 1.63 in. H_2O).

Based on Figure A.4-4, while extracting from Screen B, Zone 3 showed the best vacuum responses. While extracting from Screen B, vacuum response averages in Zone 3 ranged from 0.38 in. H_2O to 2.05 in. H_2O. Average vacuum responses for the other zones were below 0.85 in. H_2O.

Based on Figure A.4-5, while extracting from Screen C, the best average vacuum responses were recorded in Zone 4 (monitoring points were not available for Zone 4 in SVW-28,). Average vacuum responses in Zone 4 ranged from 1.20 in. H_2O to 2.95 in. H_2O. In addition, Zone 3 showed a significant average vacuum response reading while extracting from Screen C. Average vacuum responses in Zone 3 were recorded as high as 1.37 in. H_2O (SVW-25). Relatively low average vacuum responses were recorded at Zones 1 and 2.

Based on Figure A.4-6, while extracting from all three screens combined, Zones 2, 3, and 4 showed good vacuum responses. Overall, the best average vacuum responses were recorded in Zone 3 where they ranged from 0.53 in. H_2O to 2.63 in. H_2O. For Zone 2 and Zone 4, average vacuum responses ranged, respectively, from 0.0 in. H_2O to 1.9 in. H_2O and from 0.95 in. H_2O to 2.25 in. H_2O. Vacuum responses in Zone 1 were relatively low (less than 0.01 in. H_2O) with the exception of the response at SVW-26, which showed an average vacuum response of 0.95 in. H_2O.

4.1.3 Soil Permeability

Soil permeability is a measure of the ability of soil to allow airflow through its pore spaces. The following mathematical equation can be used to calculate permeability (Johnson and others, 1990):

$$\frac{Q}{H} = \pi \frac{k}{\mu} P_e \frac{[1-(P_m/P_e)^2]}{\ln(R_e/D_m)} \qquad (1)$$

Where:

Q = Flow [cfm, cm^3/s]

H = Screen interval [ft, cm]

K = Soil Permeability to air flow [darcy, cm^2]

μ = Viscosity of air [centipoise, g/cm-s]

P_e = Extraction well vacuum [inches H_2O, g/cm-s^2]

P_m = Monitoring well response [inches H_2O, g/cm-s^2]

R_e = Extraction well radius [ft, cm]

D_m = Distance of monitoring well from extraction well [ft, cm]

π = 3.14

ln = Natural logarithm

Based on equation 1, soil permeability was calculated for the test site. Using data collected during Test 1, soil permeabilities were calculated for Zones 2, 3 and 4. Soil permeability calculations are presented in Table A.4-1. Zone 2 calculations were based on vacuum response data [date and time, respectively (April 13, 1998, 12:15)] from the monitoring probes in Zone 2 of monitoring wells SVW-25, -26, and -28. Similarly, calculations for Zones 3 and 4 were based on vacuum response data (April 20, 1998, 10:00 and April 27, 1998, 14:00) from the monitoring probes in Zones 3 and 4 of monitoring wells SVW-25, -26, and -28. Results indicate that Zone 2 is the most permeable of the three zones. The estimated soil permeability value for Zone 2 is

12.60 darcy. The estimated soil permeability values for Zones 3 and 4 are 6.83 darcy and 5.72 darcy, respectively.

4.1.4 VOC Analysis

As discussed previously, the OU-2 RI (Foster Wheeler Environmental, 1999) indicated subsurface soils at OU-2 were impacted by VOCs, primarily CCl_4, Freon 113, TCE, and 1,1-DCE. The majority of the contamination extracted during Test 1 was CCl_4. Trace amounts of Freon 113 were also extracted. A total of approximately 11.1 lbs of VOCs (10.7 lbs of CCl_4 and 0.4 lbs of Freon 113) were extracted during Test 1. Extraction rate calculations are presented in Table A.4-2 and cumulative VOC removals are plotted on Figure A.4-7.

CCl_4 concentrations with respect to applied vacuum are plotted in Figure A.4-8. Since CCl_4 was at the highest concentration, only CCl_4 concentrations were plotted for the purpose of this analysis. The figure suggests that VOC concentrations did not vary significantly with vacuum during Test 1.

4.2 TEST 2

The objectives of Test 2 were to verify the vacuum responses observed during Test 1, to determine the ROI for the site, and to determine VOC removal rates trends over time.

4.2.1 Vacuum Responses

As with Test 1, vacuum responses due to the applied vacuum at the extraction well were measured at monitoring wells within the vicinity of VE-1. However, because of the high vacuum responses observed at distant soil vapor monitoring wells during Test 1, additional monitoring wells (at further distances) were observed during Test 2. Vacuum response measurements were taken at SVW-25, -26, -27, -28, -32, -33, -34, -35, -37, and -38. Since additional monitoring wells were available during Test 2, additional data were available to confirm that significant responses were present in the monitoring zones (Zones 1 to 4) at much further distances. Vacuum responses were noted as far as 771 feet away (SVW-38). Similar to Test 1, the average vacuum response in each zone with respect to distance from VE-1 was plotted for both extracting scenarios (Figures A.4-9 through A.4-10). Again, as in Test 1, the plots suggest that average vacuum responses are generally highest in the zones that correspond to the extracting well screens and decreased with distance. For example, Figure A.4-9 illustrates that when extracting from the combined Screens A, B, and C, Zones 2, 3, and 4 showed significant average vacuum response, whereas Zone 1 generally showed minimal average vacuum responses. These results, along with the decrease with distance, indeed imply that the observed vacuum responses are due to the operation of the SVE system.

To demonstrate that the observed vacuum responses were truly a function of the applied vacuum to the extraction well, vacuum response tests were performed. These tests consisted of cycling the SVE system on and off while recording vacuum responses. The results have been plotted with respect to time (Figures A.4-11 through A.4-20) and clearly show that the vacuum responses were a function of the applied vacuum. It should be noted that in these figures actual vacuum responses were plotted and not the average "zone" vacuum responses. As can be seen in Figure A.4-11 through A.4-20 when the SVE system was shut down and time was allowed for the subsurface to reach equilibrium, the vacuum responses were generally at a minimum (zero or close to zero). Also, when the SVE system was restarted, vacuum responses immediately (within 1 to 2 hours) started to rebound. Similarly, when the SVE system was shut down, vacuum responses immediately decreased in magnitude. Thus, the results of the vacuum response tests confirm that the vacuum responses in the soil vapor monitoring wells were caused by the applied vacuum at the extraction well.

4.2.2 ROI Estimation

The ROI is described as a mathematical estimate of the upper limit of distance at which the effects of extraction can be observed. These effects are usually measured as vacuum responses at the monitoring wells. Generally, the ROI is defined as the distance from the extraction well at which the response is 1.0 percent of the applied vacuum.

To determine ROI at the site, vacuum-response data was normalized and plotted as Figures A.4-21 and A.4-22. Figure A.4-21 indicates that while extracting from Screens A, B, and C combined, the ROIs for Zones 2, 3, and 4 are approximately 665, 950, and 1,000 feet, respectively. Figure A.4-22 indicates that while extracting from Screens B and C combined, the ROIs for Zones 2, 3, and 4 are 215, 900, and 900 feet, respectively.

It is recognized that these ROIs are somewhat higher than expected. As discussed in Section 4.3.3, a different approach (using actual reduction in VOC concentrations in soil vapor monitoring wells) may be warranted.

4.2.3 VOC Analysis

The majority of the contamination extracted during Test 2 was CCl_4. Trace amounts of Freon 113 were also extracted. A total of approximately 62.6 lbs of VOCs (57.0 lbs of CCl_4 and 4.6 lbs of Freon 113) were extracted during Test 2. Extraction rate calculations are presented in Table A.4-3 and cumulative VOC removals are plotted on Figure A.4-23. Generally, the data indicate that the VOC removal rates decreased with time (Figure A.4-24). While applying vacuums to Screens A, B, and C combined, the VOC removal rates ranged from 0.23 pounds per hour (lbs/hr) to 0.10 lbs/hr. While applying vacuums to Screens B and C combined, the VOC removal rates ranged from 0.11 lbs/hr to 0.08 lbs/hr.

Removal rates are a function of extracted flow rates and VOC concentration in the extracted vapors. During Test 2, the two primary carbon vessels were prematurely exhausted on two separate occasions. Testing at the carbon vendor's laboratory indicated high VOC loading although VOC removals based on laboratory analyses of the extracted soil vapor and flow rates did not indicate that carbon capacity had been reached. This indicates that one or more slugs of

VOCs may have been extracted. The amount of VOCs extracted during Tests 1 and 2, based on a 44.6 percent loading as reported by the carbon vendor, is 1,784 pounds (44.6 percent of 4,000 pounds – two vessels each with 1,000 pounds, on two occasions). Attachment 7 shows the results of the analyses on the first batch of exhausted carbon. This is only an estimate and actual VOC removal may have been lower since the analysis was based on carbon samples collected from the vessel near the inlet ports. This also includes the 73.7 pounds based on the laboratory analyes of the vapors. Hence, an estimated 800 pounds (approximately 20 percent loading) of VOCs were assumed to be removed in addition to the 73.7 pounds. Since this removal could not be substantiated by laboratory results of vapor analyses, it was not included in the removal rate calculations.

4.3 TEST 3

The objectives of Test 3 were to confirm the results of Test 2 (verification of vacuum responses, ROI, and VOC removal trends), determine the radius of remediation influence (RORI), and conduct system optimization tests.

4.3.1 Vacuum Responses

For Test 3, vacuum responses due to the applied vacuum at the extraction well were measured at monitoring wells SVW-25, -26, -27, -28, -32, -33, -34, -35, -36, -37, -38, and -39. As with Test 2, vacuum response tests were conducted to demonstrate that the observed vacuum responses were truly a function of the applied vacuum to the extraction well. As with Test 2, the results have been plotted with respect to time (Figures A.4-25 through A.4-34) and once again clearly show that the vacuum responses were a function of the applied vacuum.

4.3.2 ROI Estimation (Vacuum)

Test 3 consisted of extracting from Screens B and C combined from November 2, 1998, through September 8, 1999. The final portion of Test 3 extended from September 8, 1999, through September 22, 1999, and consisted of extracting from Screen C only. As in Test 2, the ROI is defined as the distance from the extraction well at which the response is a minimum of 1.0 percent of the applied vacuum. Plots similar to those generated for Test 2 (normalized vacuum response plots) were prepared to confirm the ROI. These are shown in Figures A.4-35 and A.4-36. Based on Figure A.4-35, while extracting from combined Screens B and C, the ROIs for Zones 2, 3, and 4 are estimated at 65, 460, and greater than 1,000 feet, respectively. Based on Figure A.4-36, while extracting from Screen C only, ROIs for Zones 2, 3, and 4 were reduced to 25, 350, and 520 feet, respectively. The results of the ROI analysis conducted for Test 2 and Test 3 indicate that the ROI for Zones 3 and 4, while extracting from combined Screens B and C is 460 feet. To be conservative, 460 feet is designated as the effective ROI for the site.

4.3.3 ROI Estimation (Remediation)

The ROI, based on vacuum response, is estimated to be on the order of 460 feet for Zones 3 and 4 while extracting from combined Screens B and C. However, this ROI may not be representative of the actual area that the extraction well is capable of remediating based on literature and previous experience. Hence, an alternate method for estimating the influence of remediation was used. This consists of estimating the "radius of remediation influence" (RORI), which is defined as the distance at which a significant the reduction of VOC levels is observed in monitoring wells (as opposed to observed vacuum responses). Since the objective of SVE is to reduce VOC levels in the subsurface, this method is expected to be more realistic than the vacuum response ROI method.

Prior to initiating Test 3 (May 1998) and after the SVE system was placed on standby (October 1999), soil vapor monitoring was conducted to evaluate SVE effectiveness. VOC percent reductions for CCl_4 and Freon 113 concentrations as of October 1999 (compared to May 1998 VOC concentrations) are plotted in Figures A.4-37 through A.4-42, for Zones 2, 3, and 4. For the purpose of this analysis, it has been assumed that an effective RORI will extend to the point of 50 percent VOC reduction. Based on this assumption, reductions of CCl_4 greater than 50 percent extend beyond 1,000 feet for Zone 2, approximately 675 feet for Zone 3, and approximately 720 feet for Zone 4. Reductions in Freon 113 greater than 50 percent have been estimated to extend beyond 1,000 feet for Zone 2, and to 340 and 380 feet for Zones 3 and 4, respectively. The results indicate that the remedial effectiveness is much greater for CCl_4 than for Freon 113. A 75% reduction in CCl_4 concentrations occurred at approximately 550 feet, 425 feet, and 450 feet away from the extraction well in Zones 2, 3, and 4, respectively. Therefore, for CCl_4, which is the primary VOC of concern, as assumed RORI (based on 75% reduction in concentrations) of 400 feet would be appropriate.

4.3.4 Pore Volume Exchange Rate

Pore volume exchange rate (PVER) is an indirect means of determining the number of SVE wells required at a site. PVER may be defined as the rate at which one complete pore volume of the impacted soil is exchanged. The number of wells required would then be based on an adequate number of pore volumes exchanged within a reasonable time frame.

For VE-1, when extracting from B and C (which corresponds to the majority of the VOC impact), the PVER is estimated as follows:

$$\text{Time for 1 pore volume exchange, days} = \frac{\pi \text{ x } \text{RORI}^2 \text{ x n x H}}{\text{Q x 1440 min/day}} \qquad (2)$$

Where:

RORI = 400 feet (it is assumed that this is the zone within which effective air exchange occurs)

n = Effective soil porosity (air), assumed to be 0.20

H = Height of soil column through which flow occurs

Q = Flow = 393 cfm

Based on the lack of vacuum responses in Zone 1, and the minimal responses in Zone 2, "H" was assumed to be equal to the thickness of Zones 3 and 4 combined, i.e., 100 feet. This translates to 1 pore volume approximately every 18 days.

4.3.5 VOC Analysis

The majority of the contamination extracted during Test 2 was CCl_4. Trace amounts of Freon 113 and TCE were also extracted. A total of approximately 125.9 lbs of VOCs (113.2 lbs of CCl_4, 11.2 lbs of Freon 113, and 2.5 lbs of TCE) were extracted during Test 2. Extraction rate calculations are presented in Table A.4-4, and cumulative VOC removals are plotted on Figure A.4-43. Test 3 results confirm Test 2 results and indicate that VOC removal rates will decrease over a long period of time (Figure A.4-44). During the initial startup of Test 3, the total VOC removal rates were as high as 0.11 lbs/hr and dropped as low as 0.004 lbs/hr (system in operation). These results indicate that VOC concentrations in the extracted vapor were reduced by over 95 percent over the duration of the test.

4.3.6 System Optimization

During Test 3, the following operational strategies were explored in order to maximize the efficiency of the SVE system (these methods involved equipment upgrades and changes in how the SVE system was being operated):

- Extracting from only Screen C to effect greater remediation in Zone 4, which is closest to the water table.
- Cycling the treatment system on and off for periods of time and monitor effects on system performance.

4.3.6.1 Screen C Extraction

On September 8, 1999, Screen B was closed off and only Screen C remained open. By closing Screen B, the applied vacuum increased from approximately 73 in. H_2O (for combined Screens B and C) to an applied vacuum of approximately 100 in. H_2O. In order to operate the SVE system at increased vacuum, the existing vapor-phase GAC adsorbers were replaced with vessels retrofitted with two reinforcement bands of the same size and configurations. The system operated for 2 weeks with only Screen C open; thus, more time may be needed to evaluate the true effectiveness under these operating parameters. However, preliminary results indicate that extracting from a single screen may reduce the radius of influence (Section 4.3.1) in certain zones.

4.3.6.2 System Cycling

In an effort to increase the system performance, cycling tests were done from May 1999 through July 1999. The VOC removal rates had decreased by approximately an order of magnitude (0.11 lbs/hr to 0.021 lbs/hr) since start-up of Test 3.

In looking at the VOC removal rate data from May through July (Figure A.4-45), the following observations can be made:

- The VOC removal rate initially rebounded following start-up of the system but the magnitude of the rebound decreased with each subsequent shutdown.
- Within each operation interval, the removal rates declined before the system was shut down.
- Overall, removal rates remained at least an order of magnitude below the levels of the initial startup of Test 3 and were consistently lower than the last period prior to cycling.

Based on these observations, cycling did not significantly enhance the performance of the SVE system. However, cycling will be continued to further evaluate its potential in enhancing effectiveness.

5.0 TEST RESULTS AND CONCLUSIONS

The test results indicated that SVE is indeed a feasible technology for remediation of the VOC-impacted soils in OU-2. Following are some of the key results of the pilot test:

- All three screens were able to extract significant quantities of soil vapor with flow-rates ranging from 157 to 174 cfm from each screen at vacuums ranging from 44 to 80 inches of water.
- Vacuum responses were noted as far as 771 feet away from the extraction well. Normalized vacuum responses of greater than or equal to 1 percent of the exerted vacuum were observed at least 460 feet away.
- A 75 percent reduction in CCl_4 (the primary constituent of interest) levels was observed approximately 450 feet away from the extraction well in Zone 4 (approximately the bottom 50 feet of the vadose zone). In Zones 2 and 3, 75 percent reductions in CCl_4 levels were observed 550 and 425 feet away from the extraction well, respectively.
- VOC concentrations in the extracted vapor were reduced by over 95 percent over the duration of the test.
- VOC removal rates of up to 0.10 lbs/hr were noted for CCl_4, with an overall removal of approximately 180 lbs of CCl_4 between May 1998 and October 1999.
- Total VOC removal rates of up to 0.11 lbs/hr were noted, with an overall removal of approximately 200 lbs between May 1998 and October 1999. An additional 850 lbs of VOCs (total) may have been removed on two separate occasions.

It should be noted that while an RORI of 400 feet is valid based on the SVE test data, a more conservative RORI may be warranted for selecting the number of wells for the full-scale system.

6.0 REFERENCES

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